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High Heat-Load Absorbers for the APS Storage Ring

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Abstract
The power density of the dipole x-rays in the 7-GeV APS storage ring is 261 watts/mrad at 300 mA of beam current. An array of absorbers is used in the ring to shield its vacuum chambers and diagnostics components in the path of these intense x-rays. This paper describes some of the unique absorber designs that were developed to handle the requirements of high power density and UHV compatibility with no water-to-vacuum joints.

Keywords: Absorbers, Storage Ring, High Heat-Load

1. Introduction

The Advanced Photon Source (APS) is a third-generation light source that provides high-brilliance x-ray beams for scientific research. At present the APS storage ring is operating at its Phase 1 specification of 7-GeV of beam energy and 100 mA of beam current. The beam current in the future will increase to its Phase 2 design value of 300 mA.

There are 80 bending dipoles of field strength 0.6 T in the 1.1-km-long storage ring. Each dipole bends the circulating electron beam by 4.5 degrees (78.5 mrad), generating a highly intense x-ray fan tangent to the beam trajectory. The vertically integrated power density of the x-ray fan is 261 watts/mrad at 300 mA. Only approximately 6 mrad of this fan exits through the exit port onto the beamline’s front-end components (see Fig. 1). The rest of the fan is intercepted by an array of high heat-load absorbers designed to protect the vacuum

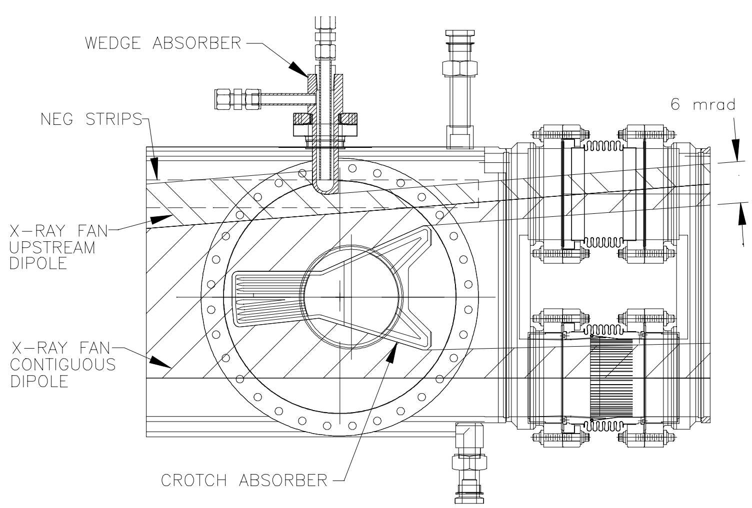

Fig. 1: Absorbers in a dipole chamber of the APS storage ring.

chambers and diagnostics components. Figure 1 shows shielding of the downstream flanges and bellows by the crotch and wedge absorbers.

In this paper we discuss guidelines that were adopted for designing the APS storage ring absorbers. Several unique absorber designs used in the ring are presented.

2. Design Guidelines

A number of design concepts were studied during the initial development phase. A beryllium ring was used as an energy diffuser [1,2] in one of the early designs. However, during the brazing tests, unacceptable voids were found in the braze joints between beryllium and oxygen-free high-conductivity (OFHC) copper [3]. A prototype was then made from beryllium copper as a casting, but this fabrication approach was also abandoned because of the possibility of voids and outgassing. Enhanced heat transfer using microchannels and porous media were evaluated by finite element (FE) models. These approaches were not pursued, however, because of the risk of clogging water passages with contaminants during the start-up phase. Clogging can also occur from deposits of cuprous oxide resulting from dissolved oxygen in deionized water.

The following guidelines were subsequently followed to develop absorber designs that were cost-effective and satisfied the requirements of high reliability and low maintenance.

- **Water-to-Vacuum Joints**: Water-to-vacuum braze or weld joints are not used. This is a general APS design requirement that was instituted to prevent water leaks from entering into the vacuum system.
- **Materials**: All high heat-load absorbers are made from Glidcop [4] because of its high thermal conductivity, high strengths at elevated temperatures, and UHV compatibility (low outgassing). OFHC copper is used for absorbers at lower power densities (i.e., farther away from the source point) when maximum temperature rise, as calculated from FE models, does not exceed 150 °C.
- **Braze Joint**: Brazing over large surface areas is avoided to eliminate the possibility of voids. To further minimize the effect of voids, braze joints are designed to be away from the region between the beam footprint and water channels. Only gold brazing (with 3565 AuCu) is used to braze Glidcop to OFHC copper or stainless steel.
- **Cooling**: Deionized water cooling (without boiling at the interface) is used for cost-effective and conservative designs. Cooling channels are designed to be within 3 to 5 mm away from the beam footprint to optimize heat transfer [5]. Water velocity in the cooling channels is kept in the 3-5 m/s range in order to keep flow-induced vibrations within acceptable levels.
- **Fatigue Life**: The absorbers are designed for a minimum fatigue life of 20,000 cycles. As a rule of thumb, this can be achieved (with a safety factor of 1.5 – 2) by limiting temperature rise to within 150 °C for OFHC annealed copper and 300 °C for Glidcop.

- **Installation:** All absorbers are assembled and indexed on flanges for quick installation in the vacuum chambers without survey and alignment. This will also allow their easy replacement in the future for inspection or upgrade.

3. Storage Ring Absorbers

The APS storage ring is divided into 40 sectors, each consisting of 6 vacuum chambers and either 9, 10 or 11 absorbers. Some of the important absorbers are described in this section.

3.1 Crotch Absorber

Crotch absorbers in the APS storage ring intercept 2/3 of the radiated power from bending magnets at a maximum normal power density of 145 watts/mm. As shown in Fig. 1, a crotch absorber consists of two distinct features: a central nose region and two side wings. Water channels and internal fins in the Glidcop body are made by the EDM (electric discharge machining) process. A copper plug, brazed in the central round opening, directs water flow to the side wings and into the internal fins of the nose.

The side wings are inclined to the incident beam by approximately 20°, thus reducing the incident power density by 66 percent. A vertical inclination of 11° is used for the nose region (Fig. 2a). In addition, 1.6-mm-deep external surface fins (Fig. 2b) are used to split the beam footprint into two parts. The fins are exposed to a fraction of the fan covered by their surface area, while the remaining fraction strikes the grooves 8 mm away. This reduces the maximum temperature rise from 350 °C to 270 °C [6].

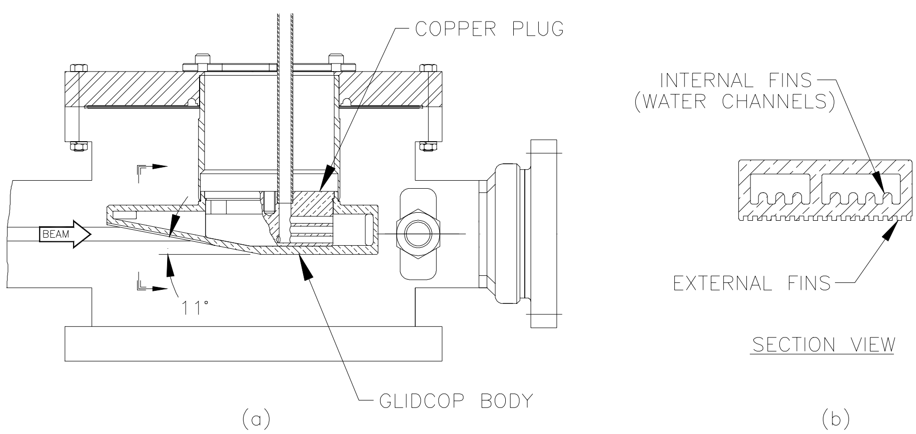

Fig. 2: A crotch absorber: (a) elevation view, (b) internal and external fins.

3.2 Beam Dump

The rf cavities and injection septum magnet occupy straight sections of 5 of the 40 storage ring sectors. These sectors have no beamlines or front ends. To absorb the 6 mrad of the x-ray fan exiting between the crotch and wedge absorbers, a beam dump is attached at the downstream end of the exit port gate valve. Normal power density at the beam dump is 36.3 watts/mm.

Figure 3 shows a compact beam dump built from a round Glidclop plate brazed inside a 6” (152 mm) flange. An elaborate pattern of channels and fins is machined on the backside of this plate to direct water flow from inlet to outlet. The channels cover ± 25 mm vertically to cover for all possible beam deviations.

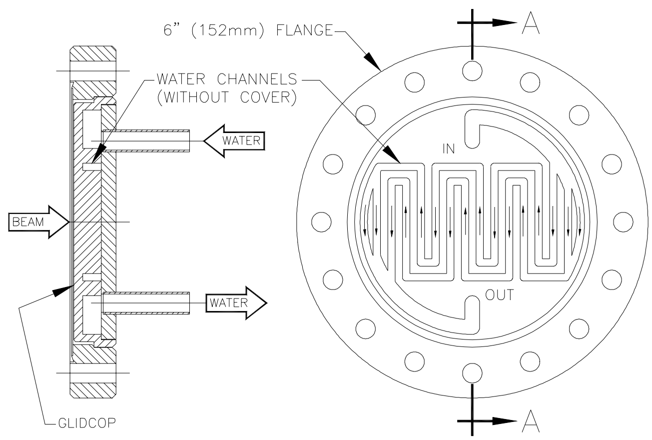

Fig. 3: A Glidcop beam dump with a pattern of machined channels.

3.3 RF Taper Absorber

The rf cavities of the APS storage ring have 140-mm circular aperture. A set of four cavities is used in each of the four rf straight sections. Downstream of the last cavity, the aperture is gradually reduced to the elliptical aperture of the vacuum chamber. A surface providing this transition would intercept x-rays from the upstream dipole at a normal power density of 26 watts/mm.

An rf taper absorber, shown in Fig. 4, absorbs this incident power while providing a smooth circular-to-elliptical transition. The transition in the Glidcop body

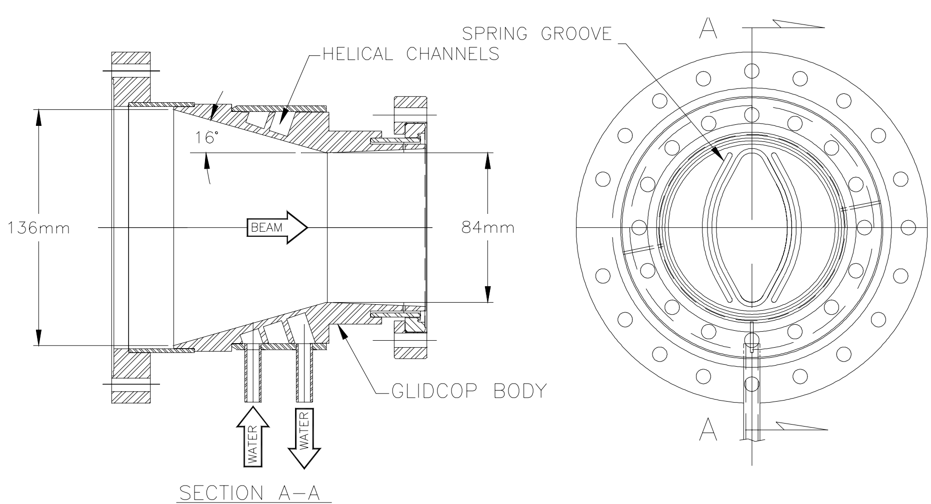

Fig. 4: An rf taper absorber with circular-to-elliptical transition.

is made by wire EDM process. Gold brazing is used to attach upstream and downstream flanges and a sleeve over helical water channels. A bevel groove for a spring is provided on the downstream side for rf continuity.

3.4 Absorber: Vertical Beam Scraper

A vertical beam scraper, consisting of upper and lower independently driven blades, is used in the storage ring for beam diagnostics. Figure 5 shows a part of the upper blade subassembly. A rectangular block of tungsten (a high Z material) is used for scraping the electron beam. Because of its poor thermal conductivity, the tungsten block cannot absorb 53 watts/mm of the incident x-ray beam power.

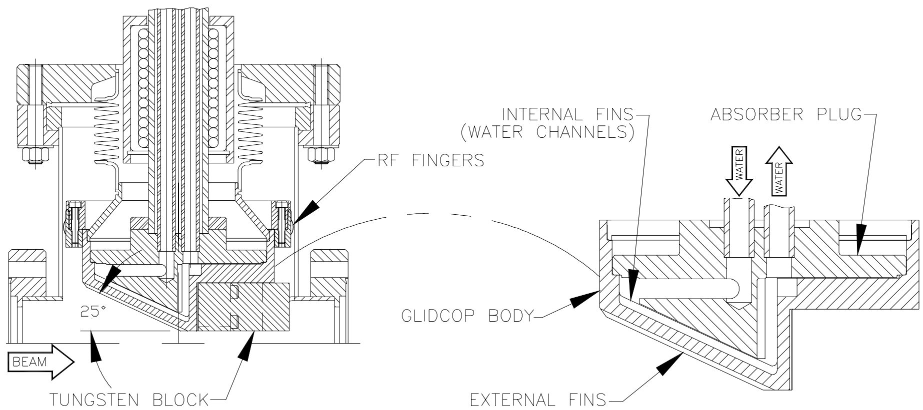

Fig. 5: An absorber shielding one of the vertical scraper blades.

To shield the tungsten block from intense x-rays, a Glidcop absorber is attached on its upstream side. The front face of the absorber intercepts the beam at 25° to reduce the incident power density. External surface fins are used (as in the crotch absorber) to split the beam footprint. Internal fins in the water channels enhance heat transfer and reduce deformations due to water pressure.

3.5 Transition Absorber

Figure 6 shows a transition absorber built within a double-sided 6”(152 mm) flange, which allows it to be inserted in tight spaces. Water tubes are brazed to the flange, to an absorber plate with an elliptical aperture, and to an external manifold. The absorber plate, made from Glidcop or OFHC copper depending on the incident beam power, is also brazed to the flange for structural strength.

The elliptical aperture is approximately 4 mm smaller all around than the nominal vacuum chamber aperture. The latter is an ellipse with major and minor radii of 42 mm and 21 mm, respectively. This absorber can, therefore, protect downstream components that fall within its shadow, which extends up to 0.5 meters for the maximum specified beam deviation of 8 mrad. A nearly parabolic profile of the elliptical aperture is selected to spread the incident beam and to reduce rf impedance of the aperture. In addition, a bevel groove is machined in the plate where an rf spring is inserted to provide rf continuity with the mating flange.

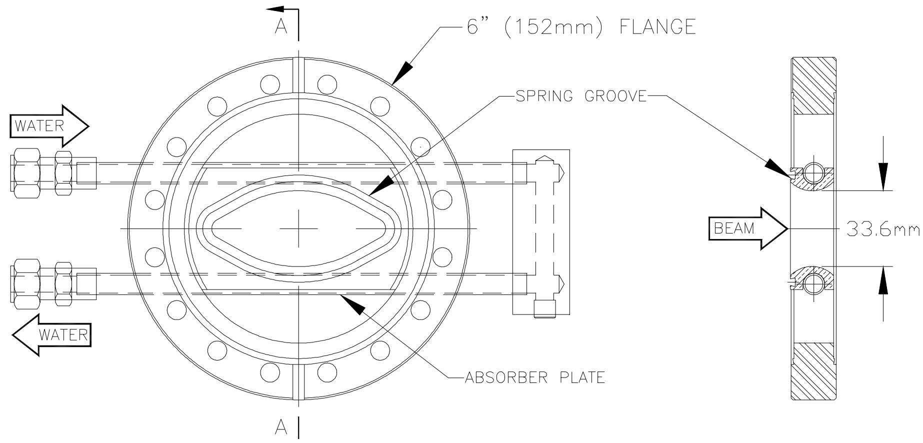

Fig. 6: A transition absorber to shadow downstream components.

4. Summary

The designs of several high heat-load absorbers for the APS storage ring have been described. These absorbers have been in service for the last several years with no failure to date. Design guidelines have been presented that led to the fabrication of cost-effective, reliable, and maintenance-free absorbers.

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